ADHOC: A Unified Approach to Parameterizing the Boundary Layer and Moist Convection

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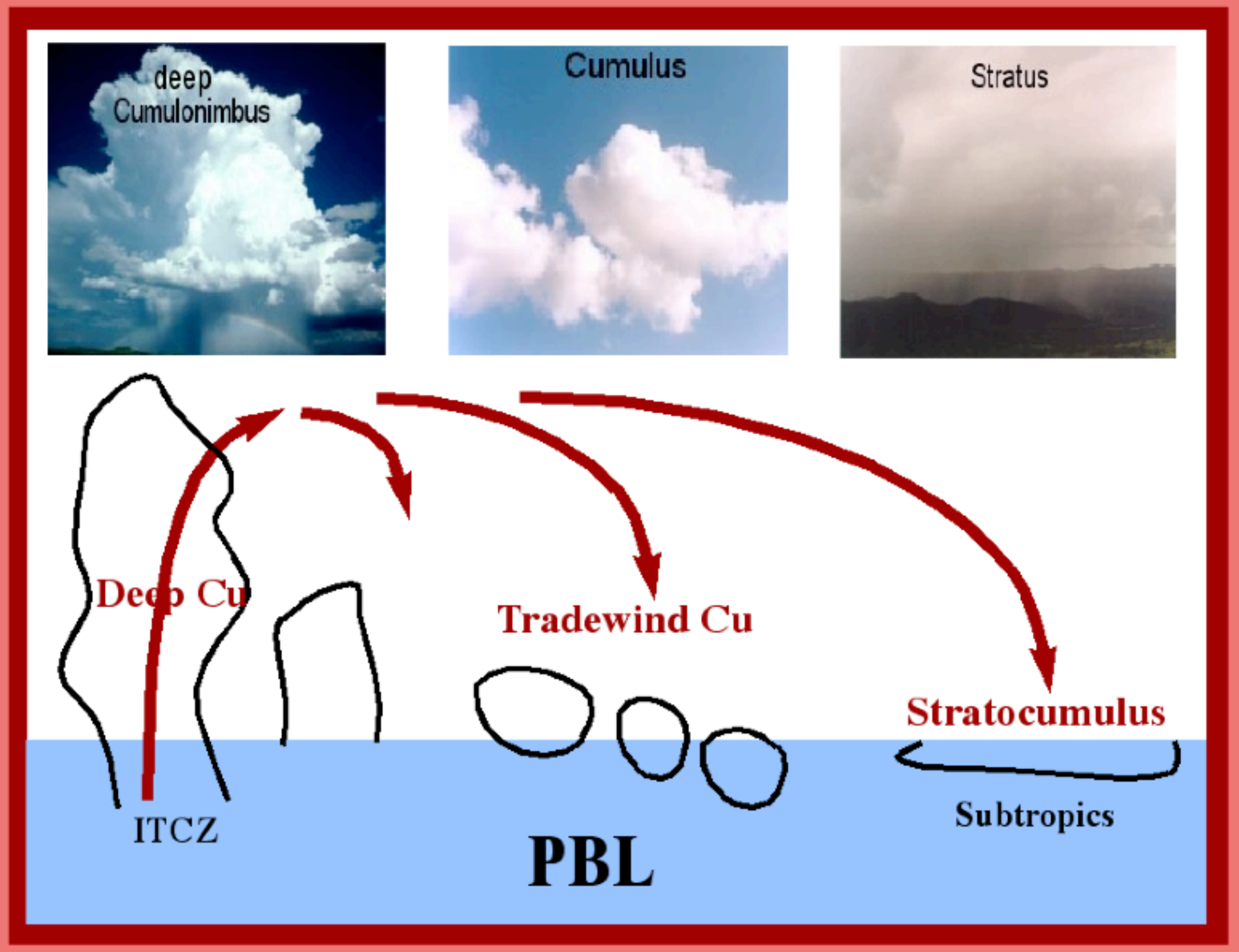
Theory

In theory, ADHOC can be used to represent all regimes in this picture.



The mass-flux formulae to the right represent the large eddy contributions to the flow. We use a subplume-scale model to represent the unresolved scale contributions.

Using Randall et al. (1992), we can write

$$\overline{w} = \sigma w_{up} + (1-\sigma) w_{dn}$$

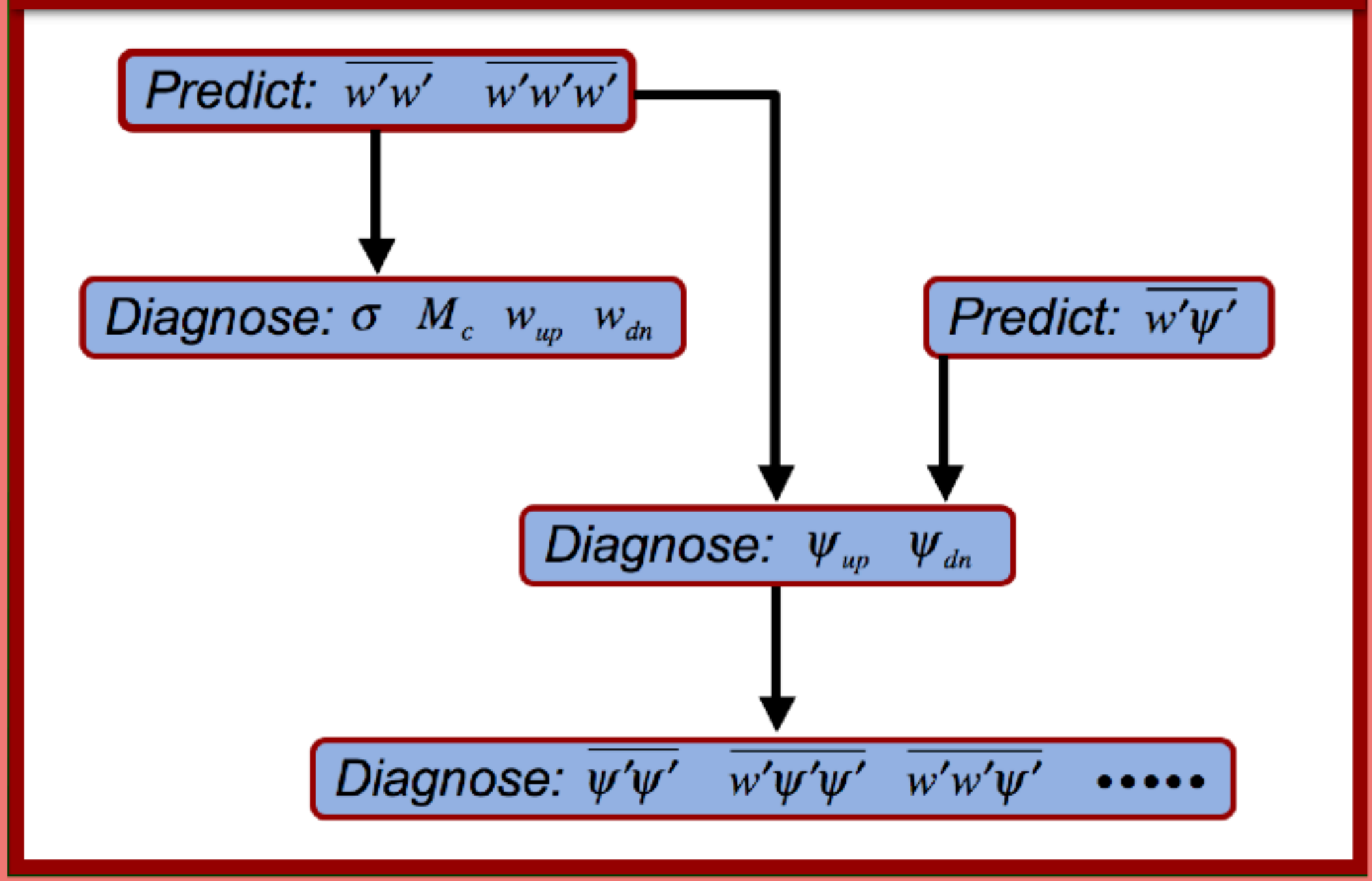
$$\overline{w'w'} = \sigma(1-\sigma)(w_{up} - w_{dn})^2$$

$$\overline{w'w'w'} = \sigma(1-\sigma)(1-2\sigma)(w_{up} - w_{dn})^3$$

We can predict the LHS using higher-order closure so the RHS can be solved for the 3 uknowns: w_{up}, w_{dn}, and σ. We then diagnose the mass flux

$$M_c = \rho\sigma(1-\sigma)(w_{up} - w_{dn})$$

ADHOC: Basic Idea



Predict: $\overline{w'w'}$ $\overline{w'w'w'}$

Diagnose: σ M_c w_{up} w_{dn}

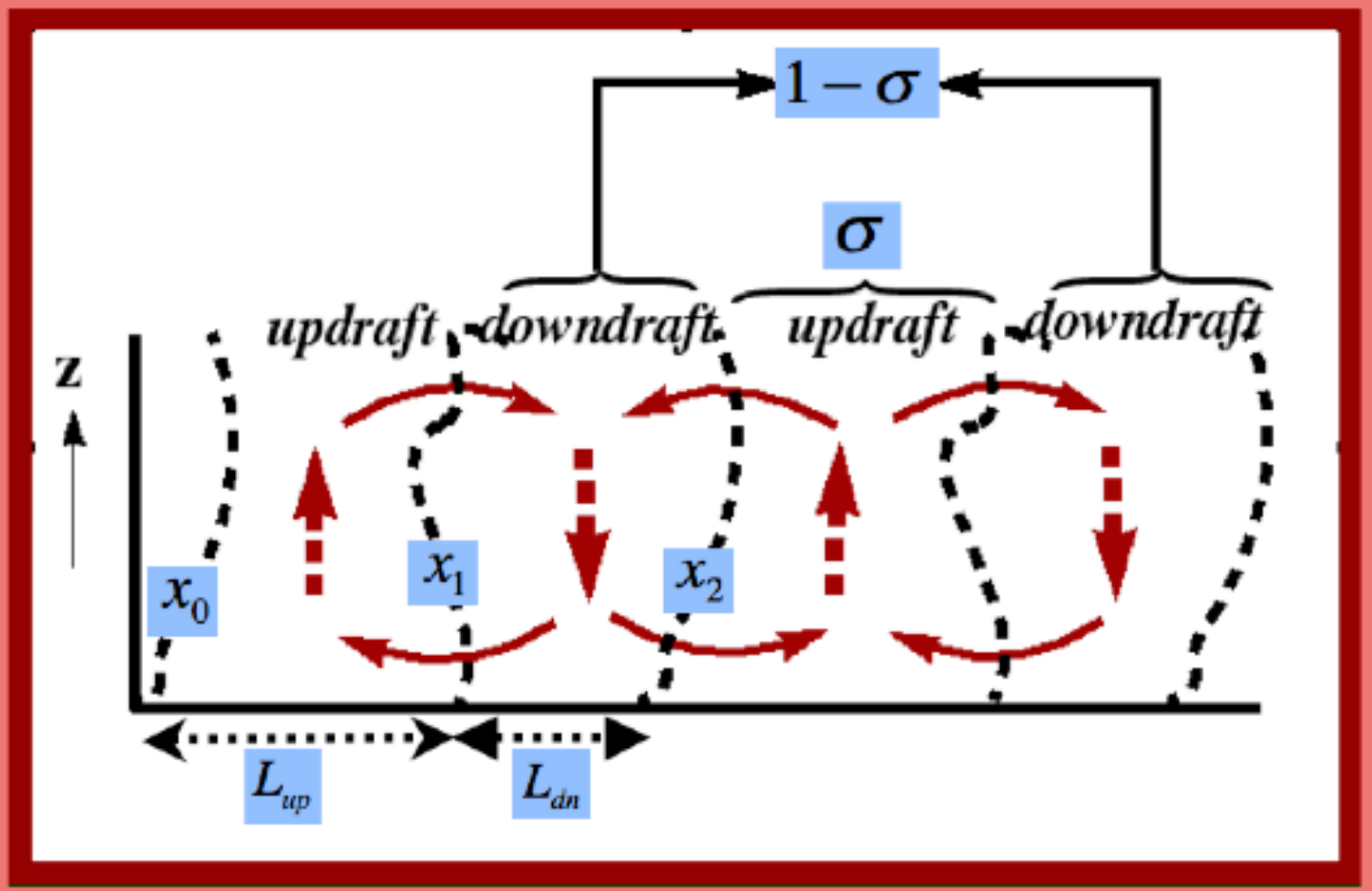
Predict: $\overline{w'\psi'}$

Diagnose: ψ_{up} ψ_{dn}

Diagnose: $\overline{\psi'\psi'}$ $\overline{w'\psi'\psi'}$ $\overline{w'w'\psi'}$ •••••

New momentum fluxes

In the original ADHOC model, the momentum fluxes were not consistent with the mass-flux framework. In our new momentum flux parameterization, we assume idealized geometries for the PBLs coherent structures, consistent with the mass-flux framework. Thus, we move away from an assumed probability distribution function (PDF) and towards an assumed spatial distribution functions (SDFs). For example, look at a sheared roll's geometry pictured to the right.



To parameterize the flux, we integrate the continuity equation over the updraft and downdraft. This gives us u(x) in the updraft. We do the same for the downdraft

$$\int_{x_0+\varepsilon}^{x_1-\varepsilon} \left[\frac{\partial u}{\partial x} + \frac{\partial w_{up}}{\partial z} \right] dx = 0$$

Now we find the average of u using u(x) from above.

$$\overline{u} = \frac{1}{L} \int_{x_0}^{x_0+L} u \, dx = \frac{1}{L} \left(\int_{x_0}^{x_0+L_u} u_{up}(x) \, dx + \int_{x_1}^{x_1+L_d} u_{dn}(x) \, dx \right)$$

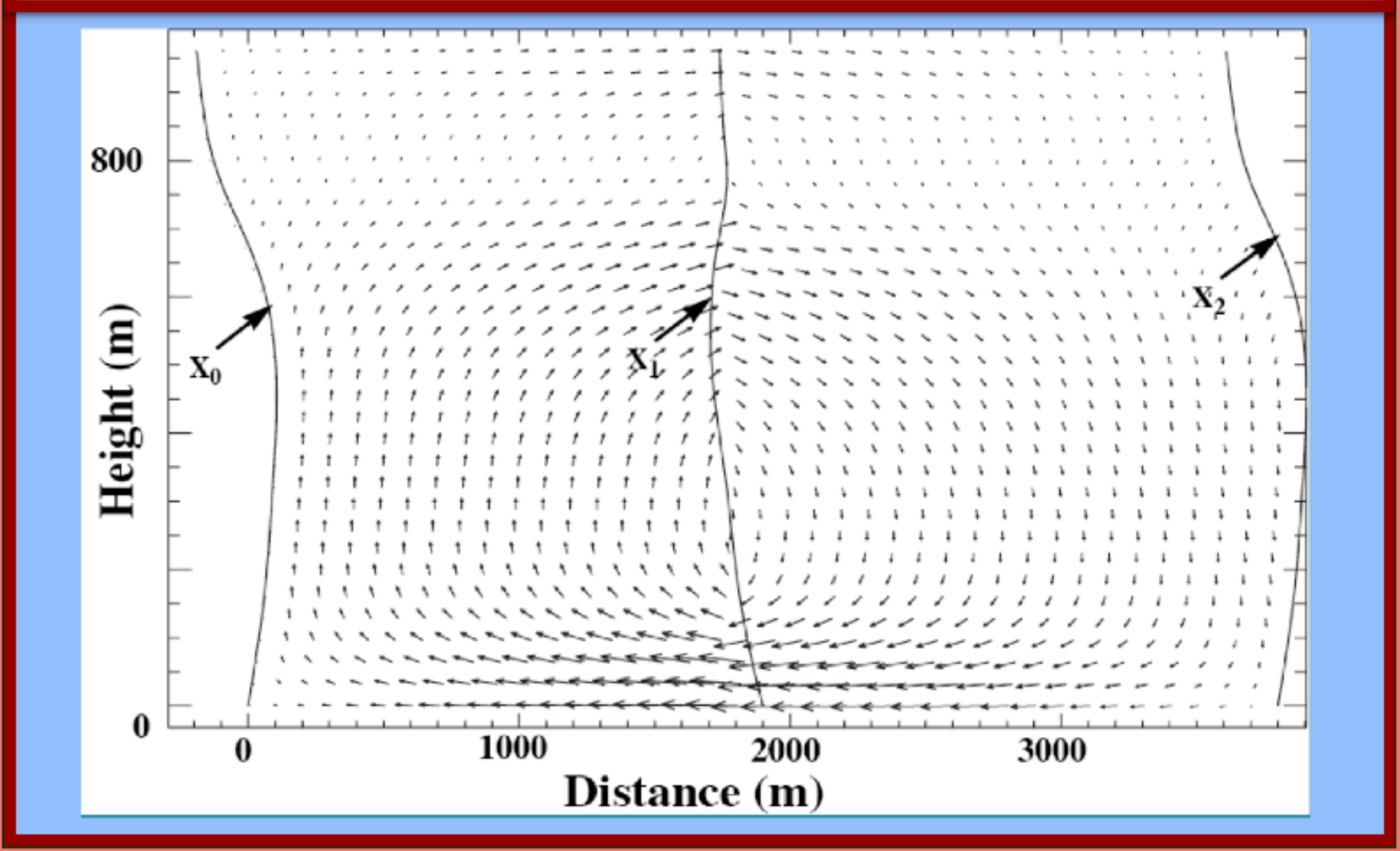
We can then calculate the momentum flux as follows

$$\overline{w'u'} = \frac{1}{L} \left(\int_{x_0}^{x_0+L_u} w_{up} u'_{up}(x) \, dx + \int_{x_1}^{x_1+L_d} w_{dn} u'_{dn}(x) \, dx \right)$$

The result is

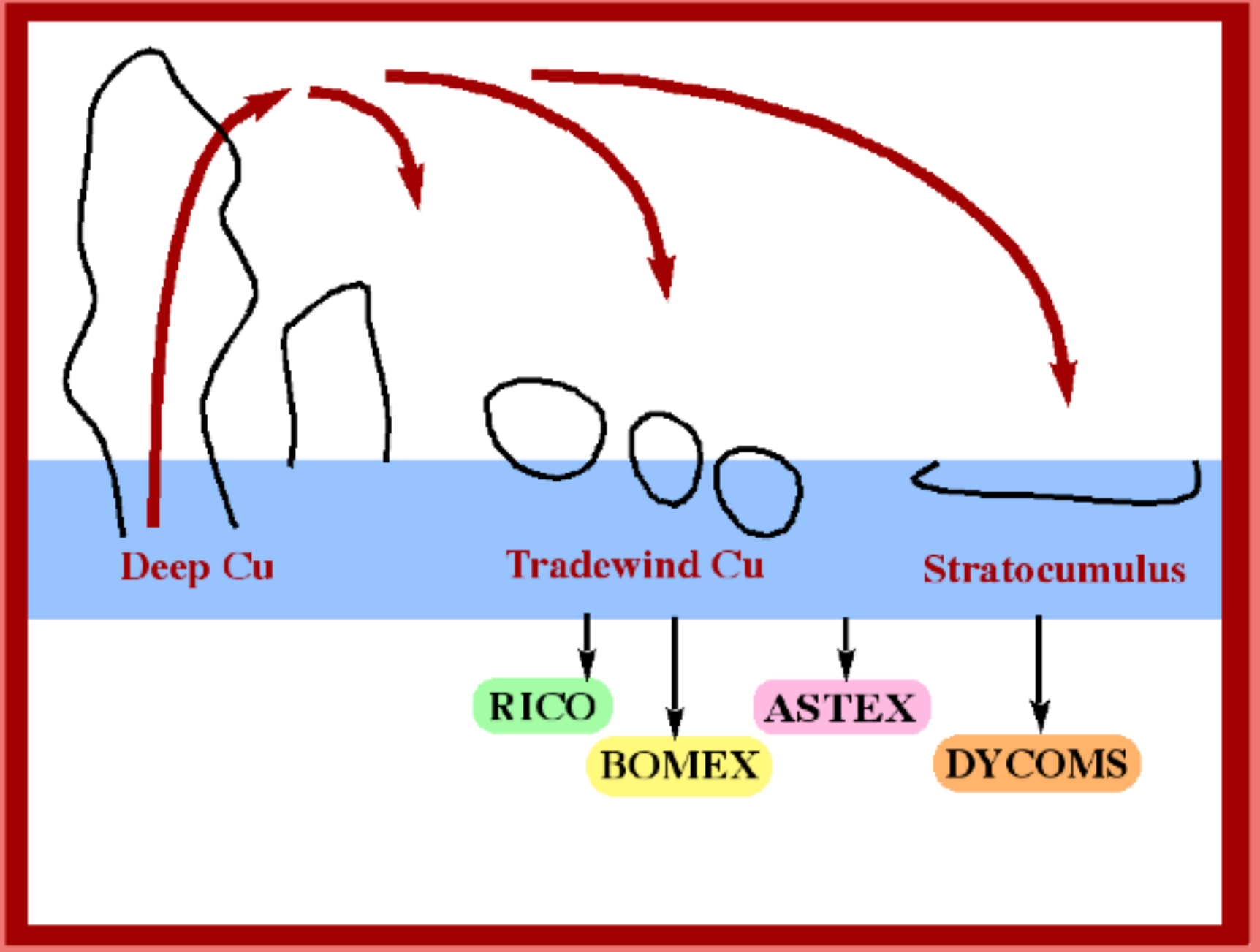
$$\overline{w'u'} = (w_{up} - w_{dn})^2 \frac{\sigma(1-\sigma)}{2} \lambda$$

Parameterized roll

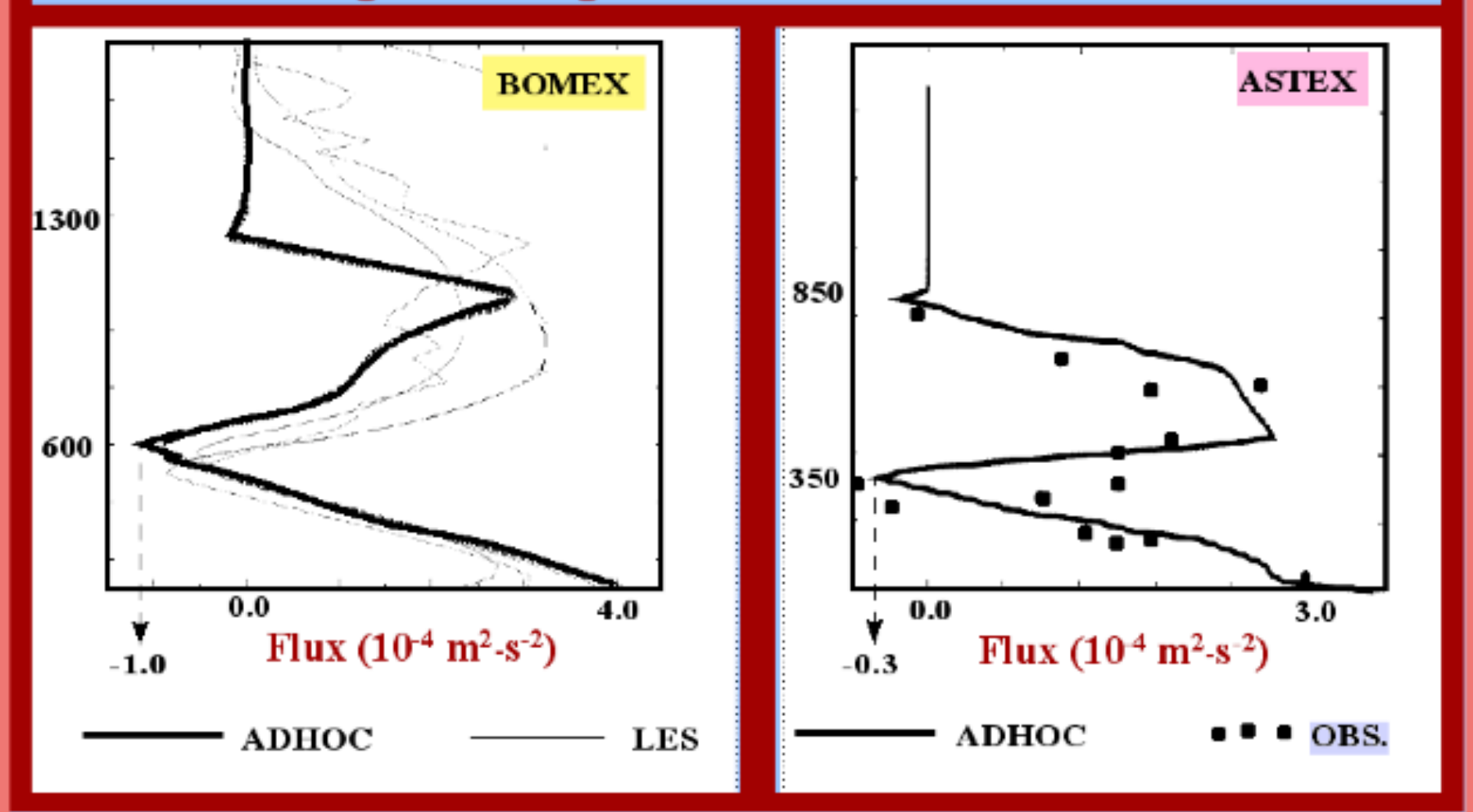


Versatility

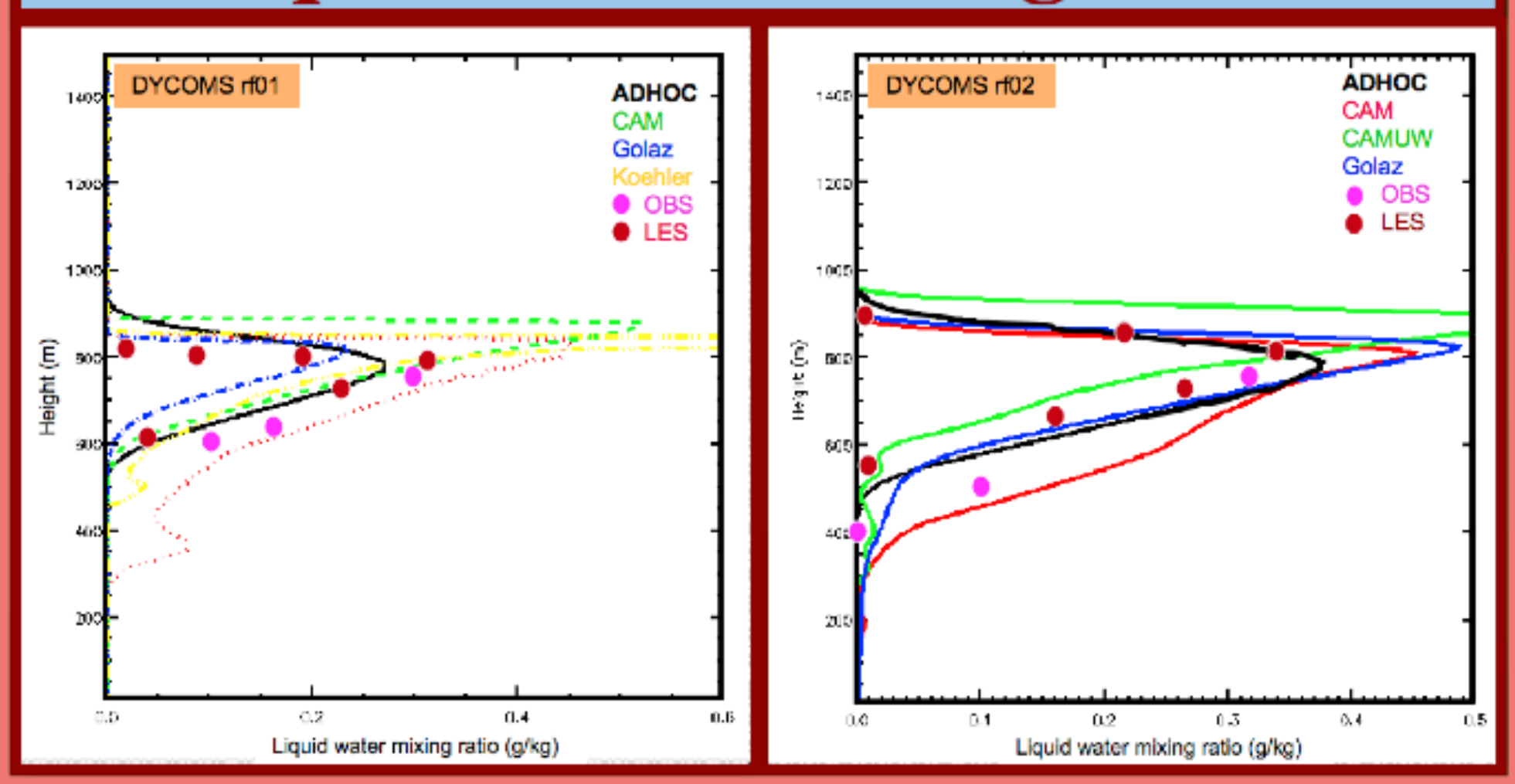
ADHOC has successfully simulated Sc (drizzling and non drizzling), shallow Cu (precipitating and not), transitional regimes between Sc and shallow Cu, dry convection, and Arctic stratus.



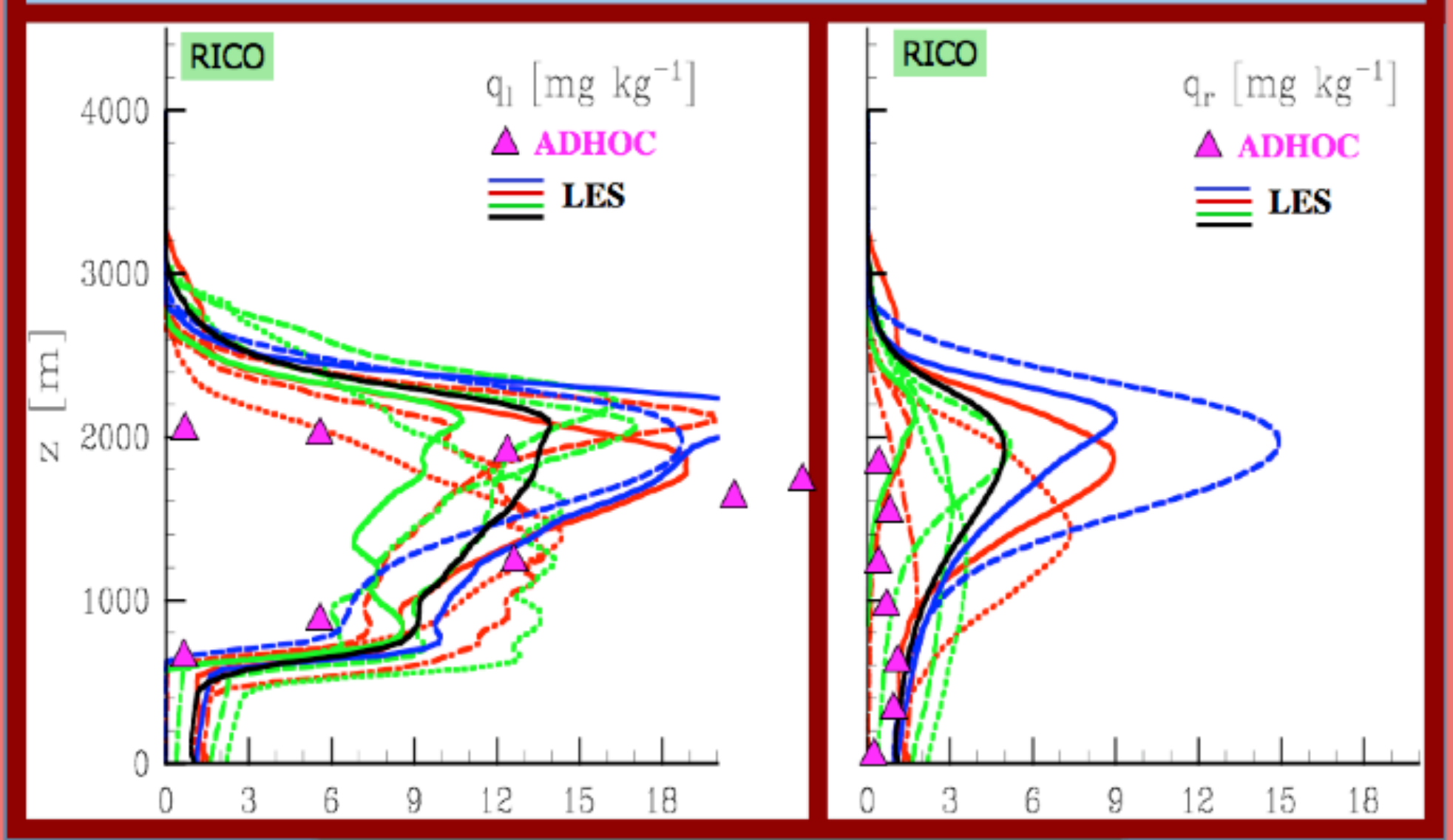
Buoyancy Flux Profiles



Liquid water mixing ratios



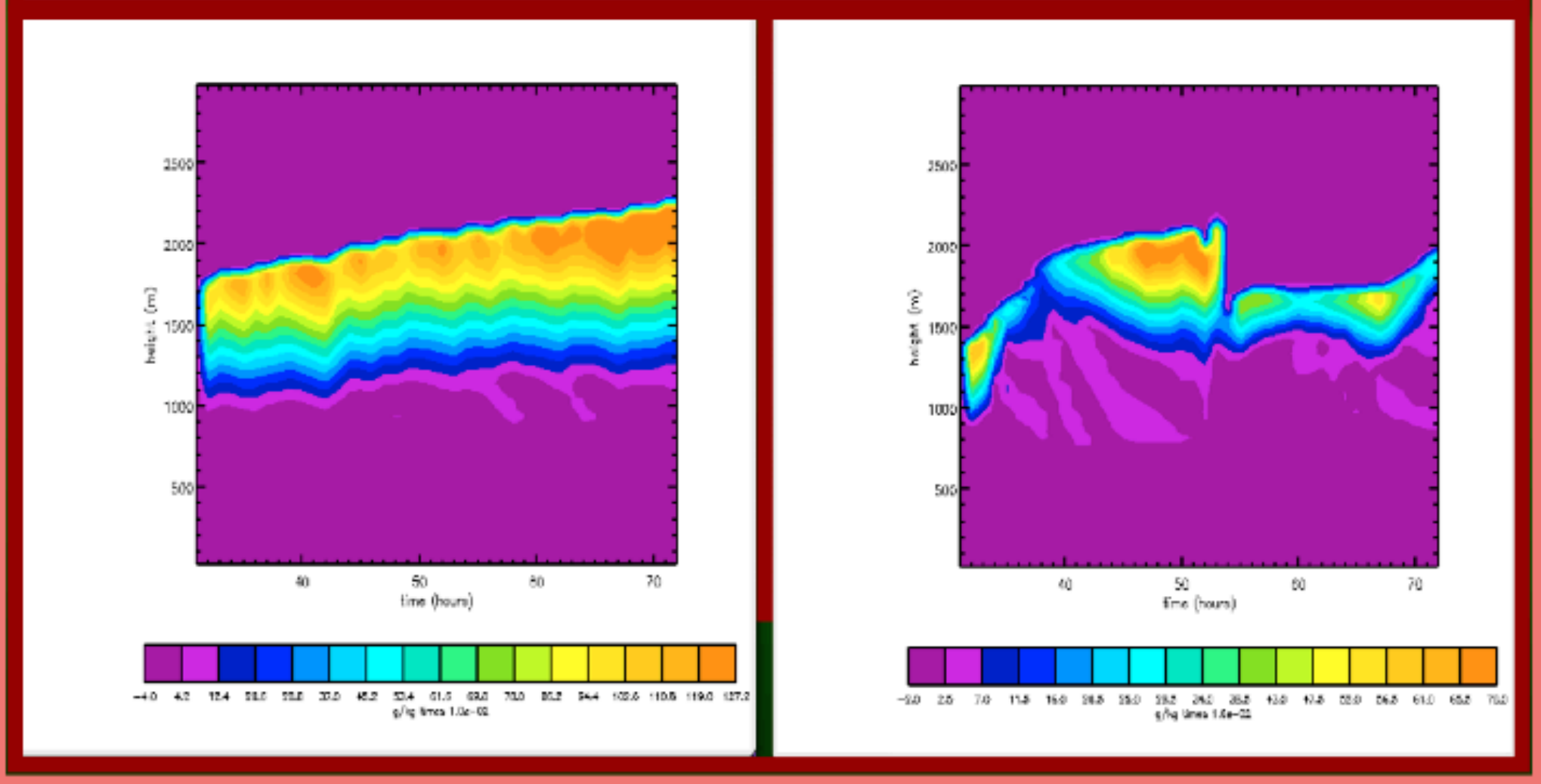
Liquid/rain mixing ratio (20-24hrs)



New precipitation scheme

We have implemented a modified version of Khairoutdinov and Randall (2003). We prognose the total precipitating and non precipitating condensate separately for updrafts and downdrafts. These are mass-flux weighted according to ADHOC's formulae. Here are some results with and without using this scheme for the RICO precipitating cumulus GCSS case. LES show the maximum mixing ratio to be about 0.3g/kg

Non-precip mixing ratio w/ and w/o precipitation scheme



Remaining issues

ADHOC needs to use longer timesteps and have larger vertical resolution. This problem will be addressed with our upcoming σ coordinate version of the model.

Using a σ coordinate, we switch from an implicit to an explicit PBL top. In doing this, we need an entrainment rate parameterization.

We would like to implement this in the CSU GCM